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FURTHER EXPLORATION OF SU(3) SYMMETRY AND EXCHANGE DEGENERACY OF BARYON REGGE RESIDUES*

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ABSTRACT

By working at wrong-signature nonsense points where background Regge poles vanish, evidence for the SU(3) symmetry of the residue of the γ (Reggeized $3/2^-$) exchanges, and new confirmations of the SU(3) symmetry of the residue of the α (Reggeized $1/2^+$) exchanges, are obtained from backward meson-baryon cross sections. Then, taking the SU(3) symmetry properties for granted, it is shown that the gross features of various backward angular distributions imply that exchange degeneracy of the baryon Regge residues is broken. Further evidence of the breaking is found in the apparent violation of a constraint in whose derivation not even Regge exchanges thought to be small are neglected. Quantitative estimates of the breaking show that residues which should be equal differ by factors of between 2 and 5. An apparent very large violation of SU(3) which cannot be attributed to exchange degeneracy breaking is noted, and its possible explanation speculated upon. Experiments which would be relevant are discussed.

I. INTRODUCTION

In a recent paper[1] (hereafter referred to as I), evidence was given for the SU(3) symmetry of baryon Regge residues.[2] That evidence was based on comparisons between the shapes of angular distributions for different backward meson-baryon reactions. Assuming the symmetry to hold, the polarization in $\pi^- p \to \Lambda K^0$ was considered, and was found to suggest that the residues of the α and γ octets are not exchange degenerate, as duality in such exotic reactions as $\bar{K}N \to N\bar{K}$ would imply, but rather have different u dependences.

In the present paper, we obtain evidence for the SU(3)-symmetric behavior of baryon Regge residues in (backward) reactions where more than one pole contributes importantly. Unwanted background poles are eliminated by working at the wrong-signature nonsense points where these poles vanish. We also obtain confirmation, from cross section data alone, that exchange degeneracy between baryon residues is indeed broken. In a pre-closing section, we note an apparent gross violation of SU(3) by the γ octet, and speculate on a possible explanation for this seeming misbehavior. Experiments that would be interesting are commented upon in the Summary. In an Appendix, we discuss the possible $\sqrt{u}$-dependence (u is the crossed momentum transfer) of the SU(3) parameter d/(d+f).

II. SU(3) AT WSN POINTS

When each of two reactions is dominated by a single Regge pole, and the two Regge poles involved belong to the same SU(3) multiplet, the SU(3) symmetry of their residues may be verified by seeing whether the cross sections for the two processes have the same u-dependence.[1] Comparison of u-dependences may also be used to verify the symmetry when in either reaction the pole of interest is accompanied by others which are rigidly related to it by exchange degeneracy (EXD). But when each of the reactions involves several unrelated poles, it is harder to check that one of those in the first raction bears an expected SU(3) relation to one of those in the second. It may still be possible, however, to isolate the poles of interest by working at a special momentum transfer where the backgrounds vanish.

We illustrate with reference to the backward reactions $\pi^+ p \to p\pi^+$ and $\pi^- p \to \Lambda K^0$. The first of these is dominated by N_α Regge pole exchange, but the second, which is pure I=1 in the u channel, can involve exchange of $\Sigma_\alpha(1190)$, $\Sigma_\gamma(1670)$, $\Sigma_\delta(1385)$, and $\Sigma_\beta(1765)$. We would like to see whether the Σ_α contribution is related to that of N_α in $\pi^+ p \to p\pi^+$ as SU(3) would require.

Duality diagrams suggest exchange "antidegeneracy" (equal trajectories with equal and opposite residues) between Σ_α and Σ_γ, and between Σ_δ and Σ_β, in $\pi^- p \to \Lambda K^0$. However, since we shall presently see that EXD is broken in this reaction, we wish to use this prediction as a rough guideline only. Applying SU(3) to the Δ_δ contribution measured in $\pi^- p \to p\pi^-$, taking into account the major kinematical SU(3)-breaking effects as in paper I, one estimates that the Σ_δ contribution to $\pi^- p \to \Lambda K^0$ at 6.2 GeV/c and u=0 is 6% of the measured rate.[3] From rough Σ_δ-Σ_β EXD and the smallness of the Σ_β signature factor relative to that of the Σ_δ in the u range of interest, the Σ_β contribution is quite a bit smaller still. Thus, Σ_α and Σ_γ must be supplying most of the observed cross section. Now if the duality diagrams are anywhere near right, the Σ_γ is <u>not</u> small compared to the Σ_α. Since we lack an accurate estimate of this Σ_γ background, we simply eliminate it by going to the u-value where $\alpha_{\Sigma_\gamma}(u) = -3/2$, and the Σ_γ contribution vanishes because of a wrong-signature nonsense (WSN) zero. From its Chew-Frautschi plot, α_{Σ_γ} passes through -3/2 at $u = -0.61$ GeV^2, so we compare the $\pi^- p \to \Lambda K^0$ rate (6.2 GeV/c data) with the $\pi^+ p \to p\pi^+$ rate (5.2 GeV/c data[4]) at this u. Neglecting at first the Σ_δ and Σ_β, the comparison follows the principles used to compare $\pi^+ p \to p\pi^+$ with $K^+ p \to pK^+$ in I, and includes a correction for the energy mismatch based on Regge power law behavior. Its result will support SU(3) symmetry if the implied d_α, the d-value for the α octet, is consistent with the values already obtained elsewhere. Normalizing d+f to unity, we find $d_\alpha = 0.66$. One can refine this value by including the Σ_δ, making some guesses about how Σ_α and Σ_δ interfere. This leads to the modified result $d_\alpha = 0.63$. Obviously, the Σ_δ has very little effect, so we make no attempt to defend our particular guesses. We observe that the value just found, 0.63, is well within the range of 0.5 to 0.8 found in the analyses of paper I. (The values of d_α deduced from various meson-baryon coupling constants cover about the same range.[5])

This procedure of making SU(3) comparisons between different reactions at WSN points has been applied to obtain additional evidence for the symmetry of the residue of the α (Reggeized $\frac{1}{2}^+$) octet, and to obtain the first evidence for symmetry of the residue of the γ (Reggeized $3/2^-$) singlet-octet mixture. Attention has been focused on the reactions $\pi^- p \leftrightarrow \Lambda K^0$, $K^+ p \to pK^+$,[6] and $\pi^- p \to \Sigma^- K^+$.[7] SU(3)-EXD estimates along the lines of the estimate made for $\pi^- p \to \Lambda K^0$ have shown that the δ (Reggeized

$3/2^+$) decuplet and β (Reggeized $5/2^-$) octet contributions are small compared to the observed cross section in all three reactions, so these contributions have been neglected. We now describe the WSN point comparisons which have been made, and their results.

Tests of α Octet Symmetry

a) We compare $\pi^- p \to \Lambda K^0$ (Σ_α and Σ_γ exchange) to $K^+p \to pK^+$, which receives contributions from Λ_α and Σ_α, and Λ_γ and Σ_γ. Neglecting the small splittings between these trajectories, we compare the rates at an average WSN point of $u = -0.7\ \mathrm{GeV}^2$, where $\alpha_{\Lambda_\gamma} \approx \alpha_{\Sigma_\gamma} = -3/2$. At this point, SU(3) for the α octet residue predicts that at a common energy

$$\frac{\sigma(\pi^- p \to \Lambda K^0)}{\sigma(K^+ p \to pK^+)} = \frac{[\sqrt{6}d_\alpha(d_\alpha - \frac{1}{2})]^2}{[(d_\alpha - 3/2)^2 + 3(d_\alpha - \frac{1}{2})^2]^2}\ , \tag{2.1}$$

where $\sigma \equiv d\sigma/du$. Correcting the 6.2 GeV/c $\pi^- p \to \Lambda K^0$ data[3] to the energy of the 5.0 GeV/c $K^+p \to pK^+$ data[6] assuming Regge pole energy-dependence, we find from (2.1) that $d_\alpha = 0.62$, in excellent agreement with the previously determined values.

b) We compare $\pi^- p \to \Sigma^- K^+$ and $K^+p \to pK^+$, both of which involve Λ_α, Σ_α, Λ_γ, and Σ_γ, but with the $\Lambda_{\alpha,\gamma}$ contributions predominating because of the weakness of the $\Sigma_{\alpha,\gamma}$ couplings. At the point where the γ contribution vanishes (this time we use $u = -0.86\ \mathrm{GeV}^2$, where $\alpha_{\Lambda_\gamma} = -3/2$), SU(3) for the α octet residue predicts that at a common energy

$$\frac{\sigma(\pi^- p \to \Sigma^- K^+)}{\sigma(K^+ p \to pK^+)} = \frac{1}{4}, \tag{2.2}$$

independent of the value of d_α. If one corrects the 5 GeV/c $K^+p \to pK^+$ data[6] to the energy of the 4 GeV/c $\pi^-p \to \Sigma^-K^+$ data[7] assuming Λ_α Regge pole energy-dependence, (2.2) predicts that $\sigma(\pi^-p \to \Sigma^-K^+;\ u = -.86\ \mathrm{GeV}^2) = 0.7\ \mu b/\mathrm{GeV}^2$. Experimentally the latter cross section is roughly $1.8\ \mu b/\mathrm{GeV}^2$, but $0.7\ \mu b/\mathrm{GeV}^2$ is still within the large error bars.

Tests of γ Singlet-Octet Symmetry

To explore the SU(3) symmetry of the residues of the γ trajectories ($N_\gamma(1520)$, $\Lambda_\gamma(1520)$, $\Sigma_\gamma(1670)$, $\cdots\cdot$), we isolate the (Λ_γ, Σ_γ) contribution in $\pi^-p \to \Sigma^-K^+$, $K^+p \to pK^+$, and $\pi^-p \to \Lambda K^0$ by going to the u-value, u_γ, where $\alpha_{(\Lambda_\alpha,\Sigma_\alpha)} = -\frac{1}{2}$ and the (Λ_α,Σ_α) contribution vanishes. (Actually, $u_\gamma \simeq +0.2\ \mathrm{GeV}^2$, which is just outside the physical region, but one can to go the nearly physical point u=0 and take the remaining α octet contribution into account.) Since the $\Lambda_\gamma(1520)$ is a singlet-octet mixture (assuming it is not more complicated still), the SU(3) prediction for relative rates at u_γ depends on the mixing angle θ, the ratio x of the γ octet Regge pole - meson - baryon coupling to the γ singlet Regge pole-meson-baryon coupling, and the d-value, d_γ, for the γ octet. Obviously, no simple predictions are possible; however, all the required SU(3) parameters may be determined from the properties of the $3/2^-$ resonances which lie along the γ trajectories. The quantities θ and d_γ have been given as 23° and 0.22, respectively.[8] The branching ratios

$$\frac{\Gamma(\Lambda(3/2^-,\ 1520) \to \pi\Sigma)}{\Gamma(\Lambda(3/2^-,\ 1520) \to \bar{K}N)}$$

and

$$\frac{\Gamma(\Lambda(3/2^-,\ 1690) \rightarrow \pi\Sigma)}{\Gamma(\Lambda(3/2^-,\ 1690) \rightarrow \bar{K}N)}\ ,$$

together with the assumption that SU(3)-symmetric couplings are related to decay rates through barrier factors $q^{2\ell+1}$,[1,8] then imply that $x \simeq 0.3$ at the position of the $3/2^-$ Λ resonances. Now SU(3) does not require that the singlet and octet couplings vary in the same manner as one goes from the positive u where the $3/2^-$ resonances occur to the negative u values corresponding to backward scattering. However, if the γ contribution is exchange degenerate with that of the α in two reactions involving different admixtures of γ singlet and γ octet, then the singlet and octet couplings must have the same $\sqrt{u}$-dependence, and x will have the same value in the u-range where it is needed as it does at resonance. Relative rates may then be predicted, but the reliance of the predictions on EXD must not be forgotten.

Neglecting the small splittings between the Λ and Σ trajectories involved, the cross section for $\pi^- p \rightarrow \Sigma^- K^+$, $K^+ p \rightarrow pK^+$, or $\pi^- p \rightarrow \Lambda K^0$ has the form

$$\sigma(s,u) = [h_\alpha^2(u)\cos^2 \tfrac{\pi}{2}\,\bar{\alpha}(u) + h_\gamma^2(u)\sin^2 \tfrac{\pi}{2}\,\bar{\alpha}(u)]\Gamma^2(-\bar{\alpha})(\tfrac{s}{s_o})^{2\bar{\alpha}(u)-1}, \qquad (2.3)$$

where $\bar{\alpha}$ is the common Λ_α, Σ_α, Λ_γ, Σ_γ trajectory, minus one-half, and s_o is a scale constant. The contributions of the α and γ multiplets are, respectively, the h_α and h_γ terms of (2.3). The h's are related to the corresponding Regge residues, and the α and γ contributions do not interfere because the trajectories are (empirically) degenerate, and the even (α) and odd (γ) signature factors then become perpendicular.

a) We compare $\pi^- p \to \Sigma^- K^+$ and $K^+ p \to pK^+$ at u=0. We assume that in $K^+ p \to pK^+$, whose s channel is exotic, the α and γ contributions are approximately exchange degenerate; that is, $h_\alpha(K^+ p \to pK^+;\ u) \cong h_\gamma(K^+ p \to pK^+;\ u)$. We shall not assume EXD, however, in $\pi^- p \to \Sigma^- K^+$, where only the t channel is exotic. Then, from (2.3),

$$\frac{\sigma(\pi^- p \to \Sigma^- K^+; s, u=0)}{\sigma(K^+ p \to pK^+; s, u=0)} =$$

$$= \frac{h_\alpha^2(\pi^- p \to \Sigma^- K^+; u=0)}{h_\alpha^2(K^+ p \to pK^+; u=0)} \cos^2 \frac{\pi}{2} \bar{\alpha}(0) + \frac{h_\gamma^2(\pi^- p \to \Sigma^- K^+; u=0)}{h_\gamma^2(K^+ p \to pK^+; u=0)} \sin^2 \frac{\pi}{2} \bar{\alpha}(0). \tag{2.4}$$

Experimentally, at the energy of the 4 GeV/c $\pi^- p \to \Sigma^- K^+$ measurements,[7] one has[6,9]

$$\frac{\sigma(\pi^- p \to \Sigma^- K^+; s, u=0)}{\sigma(K^+ p \to pK^+; s, u=0)} = 0.17.$$

From the measured cross sections[6,7] at the point where α = -3/2, the ratio

$$\frac{h_\alpha^2(\pi^- p \to \Sigma^- K^+; u)}{h_\alpha^2(K^+ p \to pK^+; u)},$$

which from SU(3) is u-independent, is 0.66.[9] Then, taking $\alpha \cong \alpha_{\Lambda_\alpha} =$

$-.70 + .97u$, as indicated by the Chew-Frautschi plot, we find from (2.4) that

$$\frac{h_\gamma^2(\pi^- p \to \Sigma^- K^+; u=0)}{h_\gamma^2(K^+ p \to pK^+; u=0)} = 0.12.$$

By comparison, the SU(3) prediction for this ratio is

$$\frac{h_\gamma^2(\pi^- p \to \Sigma^- K^+; u)}{h_\gamma^2(K^+ p \to pK^+; u)} =$$

$$= \left[\frac{(\sqrt{\tfrac{1}{8}}\cos\theta - xd_\gamma \sin\theta)(\sqrt{\tfrac{1}{8}}\cos\theta + x(\tfrac{3}{2} - d_\gamma)\sin\theta) + 3x^2(1 - d_\gamma)(d_\gamma - \tfrac{1}{2})}{(\sqrt{\tfrac{1}{8}}\cos\theta + x(\tfrac{3}{2} - d_\gamma)\sin\theta)^2 + 3x^2(d_\gamma - \tfrac{1}{2})^2}\right]^2. \tag{2.5}$$

Inserting in this expression the values of θ, d_γ, and x determined from the resonance data, relying on EXD, as explained previously, to justify the assumption that x does not vary with u, one predicts that

$$\frac{h_\gamma^2(\pi^- p \to \Sigma^- K^+; u=0)}{h_\gamma^2(K^+ p \to pK^+; u=0)} = 0.11.$$

The agreement between this number and the value 0.12 determined from the high-energy cross sections is striking, especially considering how much the SU(3) prediction depends on.

b) Finally we compare $\pi^- p \to \Lambda K^0$ and $K^+ p \to p K^+$ at $u=0$. It is easily shown that for both of these reactions one may, to a very good approximation, just neglect the α contribution relative to that of the γ at this u. Then, from (2.3),

$$\frac{h_\gamma^2(\pi^- p \to \Lambda K^0; u=0)}{h_\gamma^2(K^+ p \to p K^+; u=0)} = \frac{\sigma(\pi^- p \to \Lambda K^0; s, u=0)}{\sigma(K^+ p \to p K^+; s, u=0)} .$$

Using the 6.2 GeV/c $\pi^- p \to \Lambda K^0$ and 5.0 GeV/c $K^+ p \to p K^+$ data (correcting for energy mismatch), one finds from this relation that

$$\frac{h_\gamma^2(\pi^- p \to \Lambda K^0; u=0)}{h_\gamma^2(K^+ p \to p K^+; u=0)} = 0.2.$$

If one takes the splittings between trajectories into account, a larger value is obtained. Thus, it is interesting that the SU(3) prediction, obtained as before by using resonance data <u>and relying on EXD</u>, is

$$\frac{h_\gamma^2(\pi^- p \to \Lambda K^0; u=0)}{h_\gamma^2(K^+ p \to p K^+; u=0)} = 0.0030.$$

The combination of SU(3) and EXD has failed by two orders of magnitude!

In trying to assess this result, we note that the γ contribution to $\pi^- p \to \Lambda K^0$ is pure Σ_γ: that is, it is purely from the γ octet. By contrast, the γ contributions to $\pi^- p \to \Sigma^- K^+$ and $K^+ p \to p K^+$ are both dominated by the Λ_γ, which is more singlet than octet. Thus a failure of α-γ EXD, resulting in a failure of the γ singlet and γ octet couplings to have the same $\sqrt{u}$-dependence, would have more serious consequences for our SU(3)-EXD prediction of $h_\gamma^2(\pi^- p \to \Lambda K^0)/h_\gamma^2(K^+ p \to pK^+)$ than for that of $h_\gamma^2(\pi^- p \to \Sigma^- K^+)/h_\gamma^2(K^+ p \to pK^+)$. Considering all the evidence for the SU(3) symmetry of baryon residues, we suspect that it is indeed a breaking of EXD which is responsible for the spectacular failure of the one prediction to which EXD is most crucial.

III. CROSS SECTION TESTS OF EXD

The analysis in paper I of the polarization in $\pi^- p \to \Lambda K^0$ suggested that exchange degeneracy between the α and γ octets is broken; in particular, it suggested that the α and γ octet residues have different $\sqrt{u}$-dependences. Mindful of the caution with which conclusions based on polarizations must be treated, we now ask what can be learned about the exchange degeneracy properties of baryon Regge residues from cross section data alone. We have just seen an indication of EXD breaking in the previous section, but we seek more direct evidence than that.

Consider again the reactions $K^+ p \to pK^+$, $\pi^- p \to \Sigma^- K^+$, and $\pi^- p \to \Lambda K^0$, noting now that in each of these processes there is a reason to expect EXD of the u-channel trajectories. In $K^+ p \to pK^+$ the s channel is exotic, in $\pi^- p \to \Sigma^- K^+$ the t channel is exotic, and in $\pi^- p \to \Lambda K^0$, EXD is suggested by duality diagrams. Next, recall that the cross section for each of these reactions has the form (2.3), with $\bar{\alpha}$ a single trajectory function (neglecting small splittings) common to the three reactions. Now SU(3) tells us that the coefficients $h_\alpha^2(u)$ of the α octet contributions in the different processes are proportional to each other. If, in addition, the α and γ contributions in each process are exchange degenerate (i.e., $h_\alpha^2(u) = h_\gamma^2(u)$), then, from (2.3), the cross sections for all three processes must obviously have the same u-dependence at any given energy.

Experimentally, each of these reactions has a roughly exponential backward peak. At 6 GeV/c, these peaks have approximately the slopes indicated below (with u in GeV^2):[3,6,7,10]

$$
\begin{aligned}
K^+p &\to pK^+ : e^{4u} \\
\pi^-p &\to \Sigma^-K^+ : e^{2u} \\
\pi^-p &\to \Lambda K^o : e^{6u} .
\end{aligned}
\tag{3.1}
$$

Over a range of 1 GeV^2 in u these differences in slope are quite significant. Thus, just from the gross features of the backward cross sections we learn that exchange degeneracy between baryon residues is broken. We have, to be sure, used SU(3) symmetry in arriving at this conclusion, but we have quite a bit of evidence by now that this symmetry holds.

In the preceding argument, the δ decuplet and β octet contributions have, of course, been neglected. That the Σ_δ contributions to the reactions of (3.1) are small is found, it will be recalled, by applying SU(3) to the Δ_δ exchange which dominates $\pi^-p \to p\pi^-$. Considering the evidence for SU(3), including comparisons between strange and non-strange exchanges, one then expects that the Σ_δ contributions really <u>are</u> small. That the Σ_β, Λ_β contributions are also small then follows from the assumption that they are at least very roughly exchange degenerate with those of the Σ_δ. Thus, the neglect of the δ and β contributions should be perfectly valid. Nevertheless, it is interesting that one can find evidence that EXD is broken even if one allows these contributions to be arbitrarily large.

Assuming EXD, and only those SU(3) relations which connect various strange exchanges, one may easily show that the differential cross sections for the processes in (3.1) have the form[11]

$$\sigma_p \equiv \sigma(K^+p \to pK^+;s,u) = (\vec{\alpha} + \vec{\delta})^2, \tag{3.2a}$$

$$\sigma_\Sigma \equiv \sigma(\pi^-p \to \Sigma^-K^+;s,u) = \tfrac{1}{4}\vec{\alpha}^2 + \vec{\delta}^2, \tag{3.2b}$$

$$\sigma_\Lambda \equiv \sigma(\pi^-p \to \Lambda K^o;s,u) = \mu^2\vec{\alpha}^2 + 6\vec{\delta}^2. \tag{3.2c}$$

In (3.2), $\vec{\alpha} = (\alpha_+,\alpha_-)$ is a real, two-dimensional vector, with $\alpha_+(\alpha_-)$ representing the combined $\alpha\gamma$ contribution to the non-flip (flip) amplitude in $K^+p \to pK^+$. Similarly, $\vec{\delta} = (\delta_+,\delta_-)$ gives the combined $\delta\beta$ contribution to $K^+p \to pK^+$. The coefficient μ^2 is the d_α-dependent ratio on the right-hand side of (2.1).

From (3.2b) and (3.2c), one sees that, given μ^2, σ_Σ and σ_Λ determine the sizes of the vectors $\vec{\alpha}$ and $\vec{\delta}$ at each s and u. Then (3.2a) requires that σ_p lie in the range $(|\vec{\alpha}| - |\vec{\delta}|)^2 \le \sigma_p \le (|\vec{\alpha}| + |\vec{\delta}|)^2$. This requirement may be expressed as the constraint that

$$[(\tfrac{3}{2}\sigma_p - 6\sigma_\Sigma + \tfrac{3}{4}\sigma_\Lambda) - \mu^2(\sigma_p - \sigma_\Sigma)]^2 \le (6\sigma_\Sigma - \sigma_\Lambda)(\sigma_\Lambda - 4\mu^2\sigma_\Sigma). \tag{3.3}$$

Focussing on the point $u=0$, we find that at a pion lab. momentum of 4 GeV/c, where the cross sections are known,[12] this constraint is substantially violated for any possible value of μ^2 (see Figure 1).

To be sure, (3.3) is satisfied at $u=0$ if, for example, σ_Σ is 25% larger than the value suggested by the data of Ref. 7. Such errors are entirely possible, but the data then suggest (though not conclusively) that (3.3) cannot simultaneously be satisfied at a large u such as -0.7 GeV^2. Such simultaneous satisfaction requires, e.g., $\sigma_\Sigma \propto e^{2.5u}$ and $\sigma_p \propto e^{2.9u}$, whereas experimentally[12] $\sigma_\Sigma \propto e^{(1.45\pm0.8)u}$ and $\sigma_p \propto e^{(3.15\pm0.2)u}$. Obviously more accurate data would help; however, even through (3.3) is not presently decisive by itself, it strengthens the conclusion that EXD is broken, drawn from the comparison of u-dependences in (3.1). That comparison is not sensitive to experimental uncertainties, there being very little possibility that all three of the cross sections considered in (3.1) have the same shape.

Let us now obtain a quantitative measure of the degree of EXD breaking. We neglect the $\delta\theta$ contributions, so the three reactions of (3.1) have cross sections of the form (2.3). Let us assume that EXD remains approximately valid in the s- exotic process $K^+p \to pK^+$, and interpret the slope disparity in (3.1) in terms of a departure from unity of the ratio $X(u) \equiv h_\gamma^2(u)/h_\alpha^2(u)$ in each of the remaining two reactions, where EXD is less strongly motivated. Turning first to $\pi^-p \to \Lambda K^o$, we apply (2.3) and the SU(3) relation that $h_\alpha^2(\pi^-p \to \Lambda K^o;u)$ and $h_\alpha^2(K^+p \to pK^+;u)$ are proportional. Then, at 6 GeV/c,

$$\sigma(\pi^-p \to \Lambda K^o;u) = A[1 + (X(\pi^-p \to \Lambda K^o;u) - 1)\sin^2 \tfrac{\pi}{2}\,\bar{\alpha}(u)]e^{4u}, \qquad (3.4)$$

where e^{4u} represents the shape of $\sigma(K^+p \to pK^+;u)$ at the same energy. From the 6.2 GeV/c data at the WSN point $\alpha = -3/2$, $A = .51\ \mu b/GeV^2$. Then, matching (3.4) to the observed cross section at u=0, one finds that

$$X(\pi^-p \to \Lambda K^0;u=0) = 5.1. \qquad (3.5)$$

If one assumes X to be a constant, (3.4) and (3.5) yield the curve shown in Fig. 2.[13] Since this curve evidently represents the data quite well, we must say that the $\pi^-p \to \Lambda K^0$ cross section provides no evidence for <u>different u-dependence</u> of h_α and h_γ in this reaction. However, the cross section does, as we see, require that EXD between h_α^2 and h_γ^2 be broken <u>in size</u> by a factor of 5.

An alternative way of estimating the degree of EXD breaking in $\pi^-p \to \Lambda K^0$ is to obtain the Σ_α contribution to this reaction by applying SU(3) to the N_α exchange which dominates $\pi^+p \to p\pi^+$, and then, following (2.3), to infer the Σ_γ term by subtracting the Σ_α from the observed cross section. In applying SU(3), we follow as usual the principles used to compare $\pi^+p \to p\pi^+$ with $K^+p \to pK^+$ in I. The ratio between the Σ_α residue in $\pi^-p \to \Lambda K^0$ and the N_α residue in $\pi^+p \to p\pi^+$, which we require, was obtained implicitly when we compared these reactions at the WSN point $\alpha_{\Sigma_\gamma} = -3/2$ (Sec. II). (From SU(3) this ratio is u-independent.) Using the 5.2 GeV/c data for $\pi^+p \to p\pi^+$,[4] we find that the Σ_α contribution to $\pi^-p \to \Lambda K^0$ at 6.2 GeV/c and u=0 is $.058\ \mu b/GeV^2$. From the measured cross section of $2.0\ \mu b/GeV^2$ at this point,[3] (2.3) with the known Σ_α, Σ_γ trajectory $\bar{\alpha}$[13] then implies that

$$X(\pi^-p \to \Lambda K^0;u=0) = 6.5. \qquad (3.6)$$

This confirms the approximate correctness of the earlier estimate, (3.5). However, we note that although the hitherto neglected splitting of ≈ 0.2 between the Σ_α and Σ_γ trajectories has no gross qualitative effects, if one takes this splitting into account in computing (3.6), he finds that the degree of EXD breaking is actually quite a bit larger. With $\alpha_{\Sigma_\alpha} \neq \alpha_{\Sigma_\gamma}$, (2.3) for $\pi^- p \to \Lambda K^0$ takes the form

$$\sigma(s,u)=[(h_\alpha^+(u))^2+(h_\alpha^-(u))^2]\cos^2 \tfrac{\pi}{2}\bar{\alpha}_{\Sigma_\alpha}\Gamma^2(-\bar{\alpha}_{\Sigma_\alpha})\left(\frac{s}{s_o}\right)^{2\bar{\alpha}_{\Sigma_\alpha}-1}$$

$$+[(h_\gamma^+(u))^2+(h_\gamma^-(u))^2]\sin^2 \tfrac{\pi}{2}\bar{\alpha}_{\Sigma_\gamma}\Gamma^2(-\bar{\alpha}_{\Sigma_\gamma})\left(\frac{s}{s_o}\right)^{2\bar{\alpha}_{\Sigma_\gamma}-1} \qquad (3.7)$$

$$-2\sin \tfrac{\pi}{2}(\bar{\alpha}_{\Sigma_\alpha}-\bar{\alpha}_{\Sigma_\gamma})[h_\alpha^+(u)h_\gamma^+(u)+h_\alpha^-(u)h_\gamma^-(u)]\cos \tfrac{\pi}{2}\bar{\alpha}_{\Sigma_\alpha}\Gamma(-\bar{\alpha}_{\Sigma_\alpha})\left(\frac{s}{s_o}\right)^{\bar{\alpha}_{\Sigma_\alpha}-\frac{1}{2}}\sin \tfrac{\pi}{2}\bar{\alpha}_{\Sigma_\gamma}\Gamma(-\bar{\alpha}_{\Sigma_\gamma})\left(\frac{s}{s_o}\right)^{\bar{\alpha}_{\Sigma_\gamma}-\frac{1}{2}}.$$

In this expression, h_α^+ and h_α^- are the coefficients of the Σ_α contributions to the non-flip and flip amplitudes, respectively, and similarly for h_γ^+ and h_γ^-. The quantities $h_{\alpha,\gamma}$ defined by (2.3) are related to the $h_{\alpha,\gamma}^\pm$ by $h_\alpha^2 = (h_\alpha^+)^2 + (h_\alpha^-)^2$, $h_\gamma^2 = (h_\gamma^+)^2 + (h_\gamma^-)^2$. With the $|\Sigma_\alpha|^2$ term in (3.7) obtained by applying SU(3) as before, the implied $|\Sigma_\gamma|^2$ term will now depend on the Σ_α, Σ_γ interference. Obviously, for given σ and $|\Sigma_\alpha|^2$, the smallest $|\Sigma_\gamma|^2$ will result if the quantities $\vec{h}_\alpha \equiv (h_\alpha^+, h_\alpha^-)$, $\vec{h}_\gamma \equiv (h_\gamma^+, h_\gamma^-)$, considered as vectors in helicity space, are anti-parallel, so that the interference term has its maximal positive value. To obtain a lower bound on the EXD breaking, we suppose these vectors do have this orientation. Working again at 6.2 GeV/c and u=0, we find in this way that $|\Sigma_\gamma|^2/|\Sigma_\alpha|^2 \geq 30$. Taking into account the various trajectory-dependent factors in (3.7),[14] this result implies that

$$X(\pi^- p \to \Lambda K^0; u=0) \equiv \frac{(h_\gamma^+(0))^2+(h_\gamma^-(0))^2}{(h_\alpha^+(0))^2+(h_\alpha^-(0))^2} \geq 24. \tag{3.8}$$

We see that EXD between the Σ_α and Σ_γ residues in $\pi^- p \to \Lambda K^0$ is badly broken indeed.

Turning now to $\pi^- p \to \Sigma^- K^+$, we find from quantities already computed in Sec. II that

$$X(\pi^- p \to \Sigma^- K^+; u=0) \equiv \frac{h_\gamma^2(\pi^- p \to \Sigma^- K^+; u=0)}{h_\alpha^2(\pi^- p \to \Sigma^- K^+; u=0)}$$

$$= \frac{h_\gamma^2(\pi^- p \to \Sigma^- K^+; u=0)}{h_\gamma^2(K^+ p \to pK^+; u=0)} \; \frac{h_\alpha^2(K^+ p \to pK^+; u=0)}{h_\alpha^2(\pi^- p \to \Sigma^- K^+; u=0)} \; \frac{h_\gamma^2(K^+ p \to pK^+; u=0)}{h_\alpha^2(K^+ p \to pK^+; u=0)}$$

$$= (0.12)(1.50)(1) = 0.18. \tag{3.9}$$

Thus, there is also a substantial breaking of α-γ EXD in $\pi^- p \to \Sigma^- K^+$, in size at least. Since the existing data involve rather large error bars, they cannot be used to test whether EXD is broken in u-dependence as well.

IV. THE N_γ PROBLEM

Our various analyses, and those of paper I, have shown rather consistently that EXD does not hold, but that SU(3) does. In the one case where SU(3) appears to fail badly (cf. Sec. II), the apparent failure can plausibly be attributed to a breakdown of EXD. However, before closing we note that our results imply another failure of SU(3) which cannot be blamed on EXD breaking. Namely, the large Σ_γ contribution which we have found to dominate $\pi^- p \to \Lambda K^0$ near u=0 implies, through SU(3) for the γ octet, an N_γ contribution to $\pi N \to N\pi$ which is very much larger than experiment will allow. At 6.2 GeV/c and u=0, the $|\Sigma_\gamma|^2$ term corresponding to the lower bound (3.8) is 1.7 $\mu b/GeV^2$. At the same energy and u, the $|N_\gamma|^2$ contribution to the cross section $\sigma((\pi N \to N\pi)_{I_u=\frac{1}{2}})$ for πN scattering with $I=\frac{1}{2}$ in the u channel[15] is then

$$|N_\gamma|^2 = \frac{27}{32} \frac{1}{[d_\gamma(d_\gamma-\frac{1}{2})]^2} |\Sigma_\gamma|^2 = 370 \ \mu b/GeV^2. \tag{4.1}$$

Here we are assuming that $\alpha_{N_\gamma}(0) \simeq \alpha_{\Sigma_\gamma}(0)$, as suggested by Chew-Frautschi plots.[14,16] Also, knowing that d_γ is approximately $\frac{1}{4}$,[8,17] we are taking it to have exactly this value, since this is the value between zero and $\frac{1}{2}$ for which $|N_\gamma|^2$ is minimized. Now Barger and Olsson[15] have calculated $\sigma((\pi N \to N\pi)_{I_u=\frac{1}{2}})$ from the πN data at 5.9 GeV/c. They find that at the N_α WSN point, $u \simeq -0.14$ GeV^2, this cross section vanishes to within an error of 1 $\mu b/GeV^2$. Since Δ_δ cannot contribute to $\sigma((\pi N \to N\pi)_{I_u=\frac{1}{2}})$, this 1 $\mu b/GeV^2$ is an upper bound on the N_γ contribution at this u. However, given the Regge pole form

$$h_\gamma^2(u)\sin^2\frac{\pi}{2}\bar\alpha_{N_\gamma}(u)\Gamma^2(-\bar\alpha_{N_\gamma})\left(\frac{s}{s_o}\right)^{2\bar\alpha_{N_\gamma}(u)-1}\quad, \tag{4.2}$$

with $s_o \approx 1\ \mathrm{GeV}^2$ and $\bar\alpha_{N_\gamma} \equiv \alpha_{N_\gamma} - \frac{1}{2} = -1.40+0.92u$,[16] the N_γ contribution of (4.1) will only decrease by about a factor of 3 as one goes from u=0 to $u = -0.14\ \mathrm{GeV}^2$, unless $h_\gamma^2(u)$ behaves spectacularly between these two points. Thus, the predicted N_γ contribution at the N_α WSN point is approximately 120 $\mu b/\mathrm{GeV}^2$, in contradiction with experiment by two orders of magnitude.

It might be thought that our estimate of $|\Sigma_\gamma|^2$ in $\pi^- p \to \Lambda K^o$ at u=0, corresponding to (3.8), might be wrong because we neglected any N_γ in $\pi N \to N\pi$ when calculating the $|\Sigma_\alpha|^2$ in $\pi^- p \to \Lambda K^o$ from which the $|\Sigma_\gamma|^2$ was inferred. However, since the $|\Sigma_\gamma|^2$ accounts for practically the whole $\pi^- p \to \Lambda K^o$ cross section at u=0, any such errors in $|\Sigma_\alpha|^2$ are insignificant. (In detail, the calculation of $|\Sigma_\alpha|^2$ requires the u-independent ratio $h_\alpha^2(\pi^- p \to \Lambda K^o;u)/h_\alpha^2(\pi N \to N\pi;u)$, and the value of $|N_\alpha|^2$ at u=0. The former was obtained by comparing the cross sections for $\pi^+ p \to p\pi^+$ and $\pi^- p \to \Lambda K^o$ at $u= -0.61\ \mathrm{GeV}^2$, where $\alpha_{\Sigma_\gamma} = -3/2$. At this point it is also true that $\alpha_{N_\gamma} \simeq -3/2$, so any N_γ contribution would vanish anyway. As for $|N_\alpha|^2$ at u=0, note that the experimental upper limit of 1 $\mu b/\mathrm{GeV}^2$ on $|N_\gamma|^2$ at the N_α zero implies, from (4.2), a limit of about 3 $\mu b/\mathrm{GeV}^2$ at u=0. The biggest N_α with which an N_γ of this maximum size can interfere to produce the observed cross section $\sigma((\pi N \to N\pi)_{I_u=\frac{1}{2}};u=0) \cong 30\ \mu b/\mathrm{GeV}^2$ has $|N_\alpha|^2 = 43\ \mu b/\mathrm{GeV}^2$. Applied to this N_α, SU(3) yields $|\Sigma_\alpha|^2 = .094\ \mu b/\mathrm{GeV}^2$ at u=0. This is larger than the value .058 $\mu b/\mathrm{GeV}^2$ quoted earlier, but if one repeats the calculation preceding (3.8), he still finds that at u=0 $|\Sigma_\gamma|^2 \geq 1.7$ $\mu b/GeV^2$.)

Given the many successes of SU(3) for baryon residues, the apparent disaster represented by the oversized predicted N_γ presumably does not mean that SU(3) itself has broken down.[18] It may be, for example, that behind the N_γ problem is an oversimplified SU(3) classification of the Reggeized $3/2^-$ states. From the point of view of the quark model, one does not expect just a single $3/2^-$ octet to which the Σ_γ can belong, but two octets and a decuplet. For the octets, the quark model predicts d-values of 3/8 and 3/2.[19] Experimentally, only one $3/2^-$ octet has been established; its d-value as we know is approximately $\frac{1}{4}$, reasonably close to the quark model prediction of 3/8. Perhaps, for some dynamical reason, the coupling of the other octet to meson-baryon states is suppressed. However, suppose that as one goes from positive u, where the $3/2^-$ resonances occur, to negative u, the Regge poles corresponding to the two $3/2^-$ octets switch roles, so that now the coupling of the octet with the small d-value is suppressed, and the octet with the large d-value dominates. In that case the d-value which should be used in (4.1) is more like 3/2 than $\frac{1}{4}$. If $d_\gamma = 3/2$ in (4.1), the $|N_\gamma|^2$ contribution at the N_α WSN point is only 0.2 $\mu b/GeV^2$, instead of 120 $\mu b/GeV^2$, and the contradiction with experiment is resolved.[20] Now we do not mean to suggest that this mechanism, in which two octets conspire to give the appearance of a single multiplet with schizophrenia, is the explanation of the N_γ puzzle. However, we offer it as an example of the interesting possibilities which the quark model suggests and which should be pursued further Note that when we verified the SU(3) relation between the Reggeized $3/2^-$ contributions to $\pi^- p \to \Sigma^- K^+$ and $K^+ p \to pK^+$, we took the Σ_γ to belong to a single octet with $d_\gamma = 0.22$, and the Λ_γ to be a mixture involving this octet and a singlet. Such analyses would have to be re-examined if the schizophrenic octet idea were explored further.

V. SUMMARY AND SUGGESTED EXPERIMENTS

By working at or near WSN points, we have been able to isolate Regge poles of interest and verify the SU(3) symmetry properties of their residues in reactions where no one Regge pole dominates. The first evidence for SU(3) symmetry of the γ (Reggeized $3/2^-$) exchanges, as well as new confirmations of the symmetry of the α (Reggeized nucleon) octet, have been obtained in this way. All tests of SU(3) at WSN points have given positive results, save for the one prediction which relies most heavily on assumed exchange degeneracy, and which is violated by two orders of magnitude. However, SU(3) also appears to fail by two orders of magnitude when one tries to relate the N_γ and the Σ_γ, assuming them to belong to a single octet with $d \simeq \frac{1}{4}$. This is taken, not as an actual breakdown of SU(3), but as evidence that, as one would expect from the quark model, these trajectories involve more than a single SU(3) multiplet.

Quite a lot of theoretical work has been based on the assumption of exchange degeneracy, both for trajectories (at least some of which are known to be degenerate from their Chew-Frautschi plots) and for residues. However, a previous examination of the polarization in $\pi^- p \to \Lambda K^0$ [1] has suggested that the Σ_α and Σ_γ residues in the exotic reaction $K^+ p \to pK^+$ are in fact not exchange degenerate. Following this suggestion, we have tried to see what can be learned about the exchange degeneracy properties of baryon residues from cross section data alone. For this purpose, the SU(3) symmetry of the residues has been taken for granted. No new evidence for different $\sqrt{u}$-dependences of residues which one would like to be exchange degenerate has been found. However, it has been discovered that the slopes of the backward peaks in $K^+p \rightarrow pK^+$, $\pi^-p \rightarrow \Sigma^-K^+$, and $\pi^-p \rightarrow \Lambda K^0$ already point clearly to a breaking of the hoped-for exchange degeneracy, in size if not in $\sqrt{u}$-dependence, between the $(\Lambda_\alpha, \Sigma_\alpha)$ contribution and that of $(\Lambda_\gamma, \Sigma_\gamma)$ in two of these reactions. Further evidence that baryon residues do not obey exchange degeneracy has come from the apparent violation of a constraint, in whose derivation possible Σ_δ and $(\Lambda_\beta, \Sigma_\beta)$ contributions are not neglected, between the cross sections for these three processes. A quantitative measure of the degree of exchange degeneracy breaking has been made. It is found that contributions to cross sections depart from the relationships expected from exchange degeneracy of residues by factors of between 5 and 24 or more. This means that the residues are breaking the degeneracy by factors of between 2 and 5. How serious this is for theories based on exchange degeneracy we do not know. It is interesting that the breaking is not by factors of 10 or 100. The exchange degeneracy between baryon Regge poles is at least working very crudely; perhaps theories based on it are still qualitatively all right.

Some experiments which would be particularly valuable from the point of view of SU(3) and EXD have already been suggested in paper I. Here we would only like to add a few comments. It is obviously of interest to try to unravel the puzzling behavior of the Reggeized $3/2^-$ exchanges. To do this, it would be useful to study reactions which allow only strange exchanges with I=1, since such processes will not be contaminated by the Λ_γ, which is a singlet-octet mixture at the least. Examples are

$$
\begin{aligned}
&K^-p \to \Xi^0 K^0 \\
&\pi^-p \to \Sigma^0 K^0 \\
&K^+n \to nK^+ \\
&K_L^0 p \to pK_s^0 .
\end{aligned}
\tag{5.1}
$$

By studying these reactions near u=0, close to the Σ_α WSN point, one can isolate the Σ_γ contributions, and see whether they are related to each other (and to the known Σ_γ contribution in $\pi^-p \to \Lambda K^0$) as one would expect for a trajectory belonging to an octet with $d \simeq \frac{1}{4}$, or, if not, how.[21] Suppose that, as speculated in Sec. IV, the Σ_γ behaves for $u \leq 0$ like a member of an octet with $d \simeq 3/2$. Then, from the observed cross section for $\pi^-p \to \Lambda K^0$ at 6 GeV/c and u=0, one expects that at the same energy and angle, the cross section for $K^-p \to \Xi^0 K^0$ will be of order 1 or 2 $\mu b/GeV^2$ (as opposed to 50 $\mu b/GeV^2$ if $d_\gamma \simeq \frac{1}{4}$), and that for $\pi^-p \to \Sigma^0 K^0$ will be less than 0.5 $\mu b/GeV^2$ (again as opposed to 50 $\mu b/GeV^2$ if $d_\gamma \simeq \frac{1}{4}$). Experimentally, we have some hints from lower energy data that both expectations will prove correct: observations of $K^-p \to \Xi^0 K^0$ at 3 GeV/c,[22] extrapolated to 6 GeV/c assuming Σ_γ Regge pole energy dependence, suggest a backward cross section in the 1 $\mu b/GeV^2$ region, while a study of $\pi^-p \to \Sigma^0 K^0$ at 4 GeV/c found a backward cross section of zero to within 1.3 $\mu b/GeV^2$.[7] It should be noted that all of the reactions in (5.1) are ones in which one might expect exchange degeneracy, and so are interesting to study for that reason. Finally, measurements of $K^-p \rightarrow \Xi^0 K^0$ would also facilitate the making of a different, relatively clean test of SU(3) symmetry.[23]

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APPENDIX: POSSIBLE $\sqrt{u}$-DEPENDENCE OF d

Both in paper I and here, it has been assumed, when considering exchange of Regge poles belonging to an octet, that the octet coupling parameter $d(\sqrt{u})/(d(\sqrt{u})+f(\sqrt{u}))$ is a constant, independent of the energy $W=\sqrt{u}$ carried by the trajectory. This assumption is not required by SU(3), and we wish to comment upon it. (Since we normalize d+f=1, we discuss d.)

If d actually varies with $\sqrt{u}$, the ratio between the values of a given spin amplitude in two different reactions will depend on u, and also on which amplitude is involved. If it happens that $d(-\sqrt{u})=d(\sqrt{u})$, then the dependence on amplitude disappears. The opposite possibility, that the ratio between different reactions depends on which of the two independent meson-baryon spin amplitudes one is considering, but not on u, seems very unlikely. We illustrate why in a trivial example.

Consider several meson-baryon reactions k, for each of which there are two independent spin amplitudes which we shall call $f^k_\pm$. Suppose that the ratios f^2_+/f^1_+ and f^2_-/f^1_- between reactions 2 and 1 are different, but u-independent. Now consider an alternative set of spin amplitudes $g^k_\pm \equiv f^k_+ \pm f^k_-$. Then, for instance,

$$\frac{g^2_+}{g^1_+} = \frac{f^2_+}{f^1_+} \cdot \frac{1 + \dfrac{f^2_-}{f^2_+}}{1 + \dfrac{f^1_-}{f^1_+}} .$$

Now the ratio f_-^k/f_+^k between the spin amplitudes in a given reaction is in general u-dependent. And under our assumptions, f_-^2/f_+^2 and f_-^1/f_+^1 differ in size. Thus, if f_+^2/f_+^1 was u-independent, g_+^2/g_+^1 will not be. And in the absence of a guideline , it seems unlikely that some particular choice of spin amplitudes will happen to be the lucky set for which ratios between different reactions depend on amplitude but not u.

When $d=d(\sqrt{u})$, then at each u the scattering depends on four quantities: $d(\sqrt{u})$, $d(-\sqrt{u})$, and $\gamma(\sqrt{u})$, $\gamma(-\sqrt{u})$, where $\gamma(\sqrt{u})$ is the SU(3)-invariant vertex defined in I.[24] Numerous measurements are then required to determine all quantities. If $d(-\sqrt{u}) = d(\sqrt{u})$ (so that SU(3) relations are amplitude-independent), the u-dependent comparison between a pair of cross sections may be used to fix d(u); then any third cross section may be predicted. But if $d(\sqrt{u})$ is just a constant, the <u>shape</u> of one cross section already follows from that of another, without any prior comparisons. In paper I it was found that predictions of one angular distribution from another, based on an assumed constancy of d_α, the d-parameter for the Reggeized $\frac{1}{2}^+$ octet, are indeed successful. Furthermore, the <u>values</u> obtained for d_α in the negative - u analyses of I and the present paper are very similar to the values deduced from meson-baryon coupling constants which correspond to $u \simeq +1$ GeV^2. These results suggest that d_α, at least, does not actually vary significantly with $\sqrt{u}$. It is then plausible that the d-parameters of other octets do not either.

FOOTNOTES

1. B. Kayser and F. Hayot, Phys. Rev. D 6, 2423 (1972). (A less complete version of this paper, based in part on unpublished data, was circulated as SLAC-PUB-1003.)
2. Evidence for this symmetry has also been given by F. Halzen, Proceedings of the 6th Rencontre de Moriond, March, 1971, J. Froyland, F. Halzen, and B. Petersson, CERN preprint TH. 1255, V. Barger, Coral Gables Conference on Fundamental Interactions at High Energy, January, 1969, A. Martin and C. Michael, Phys. Letters 32B, 297 (1970), V. Barger, F. Halzen, and M. Olsson, Wisconsin preprint, and others.
3. W. Beusch et al., Nucl. Phys B19, 546 (1970).
4. W. Baker et al., Phys. Letters 28B, 291 (1968).
5. R. Field, Jr. and J. D. Jackson, Phys. Rev. D 4, 693 (1971), Fig. 4.
6. V. Chabaud et al., Phys. Letters 38B, 445 (1972).
7. O. Dahl et al., Phys. Rev. 163, 1430 (1967).
8. E. Flaminio et al., Brookhaven preprint BNL 14572 (March, 1970).
9. The 5 GeV/c data of Ref. 6 are corrected to the energy of the 4 GeV/c data of Ref. 7 as before.
10. The slopes of the 4 GeV/c $\pi^- p \rightarrow \Sigma^- K^+$ and 5 GeV/c $K^+ p \rightarrow p K^+$ data have been corrected slightly for energy mismatch.
11. In obtaining (3.2b) and (3.2c), one uses the empirical fact that

$$\alpha_{\Sigma_\delta} \cong \alpha_{(\Lambda_\alpha, \Sigma_\alpha, \Lambda_\gamma, \Sigma_\gamma)} + \tfrac{1}{2}.$$

12. σ_Λ and σ_Σ are reported for this energy in Refs. 3 and 7, respectively, and σ_p may be corrected to this energy from the 5 GeV/c data of Ref. 6 as before.

13. We use $\bar{\alpha} \cong \bar{\alpha}_{\Sigma_\alpha} \cong \bar{\alpha}_{\Sigma_\gamma} = -1.36 + .9u$.

14. From resonance data tables, we have $\alpha_{\Sigma_\alpha} = -0.77+0.90u$, $\alpha_{\Sigma_\gamma} = -0.96+0.88u$. We use $s_o = 1$ GeV^2, as explained in paper I.

15. V. Barger and M. Olsson, Phys. Rev. D 5, 2736 (1972), and V. Barger, F. Halzen, and M. Olsson, Ref. 2.

16. V. Barger and D. Cline, Phys. Rev. 155, 1792 (1967).

17. J. Meyer and D. Plane, Nucl. Phys. B25, 428 (1971).

18. As remarked earlier, it cannot be blamed on EXD breaking either, since EXD has not been assumed, except when very rough EXD was used to conclude that Σ_β is small in $\pi^- p \to \Lambda K^o$ because Σ_δ is. Even a very large breaking of this EXD would not change the basic conclusion that N_γ is too large. Note also that, even if $|\Sigma_\beta|^2$ is 25 times larger than EXD would say, the observed value $d \simeq 5/4$ for the β octet (Ref. 17) implies an $|N_\beta|^2$ of less than 0.5 μb/GeV^2 in $(\pi N \to N\pi)_{I_u=\frac{1}{2}}$ for -0.6 GeV^2 $< u < 0.0$ GeV^2.

19. S. Meshkov, Proceedings of the International Conference on Duality and Symmetry in Hadron Physics, Tel Aviv University, April, 1971 (Weizmann Science Press).

20. In the quark model, the $5/2^-$ octet and the $3/2^-$ octet with $d = 3/2$ should have the same d-value. Experimentally, the former multiplet has $d \simeq 5/4$ (cf. Ref. 17). If we suppose that the latter multiplet also has $d = 5/4$, and use this value in (4.1), we obtain an $|N_\gamma|^2$ of 0.5 μb/GeV^2 at the N_α WSN point, again perfectly compatible with experiment.

21. From SU(3) and rough EXD, the Σ_δ and Σ_β contributions will be neglig-

ible in any reaction in (5.1) whose cross section does not prove to be substantially smaller than that for $\pi^- p \to \Lambda K^0$.

22. J. Badier *et al.*, Saclay preprint CEA-R3037.

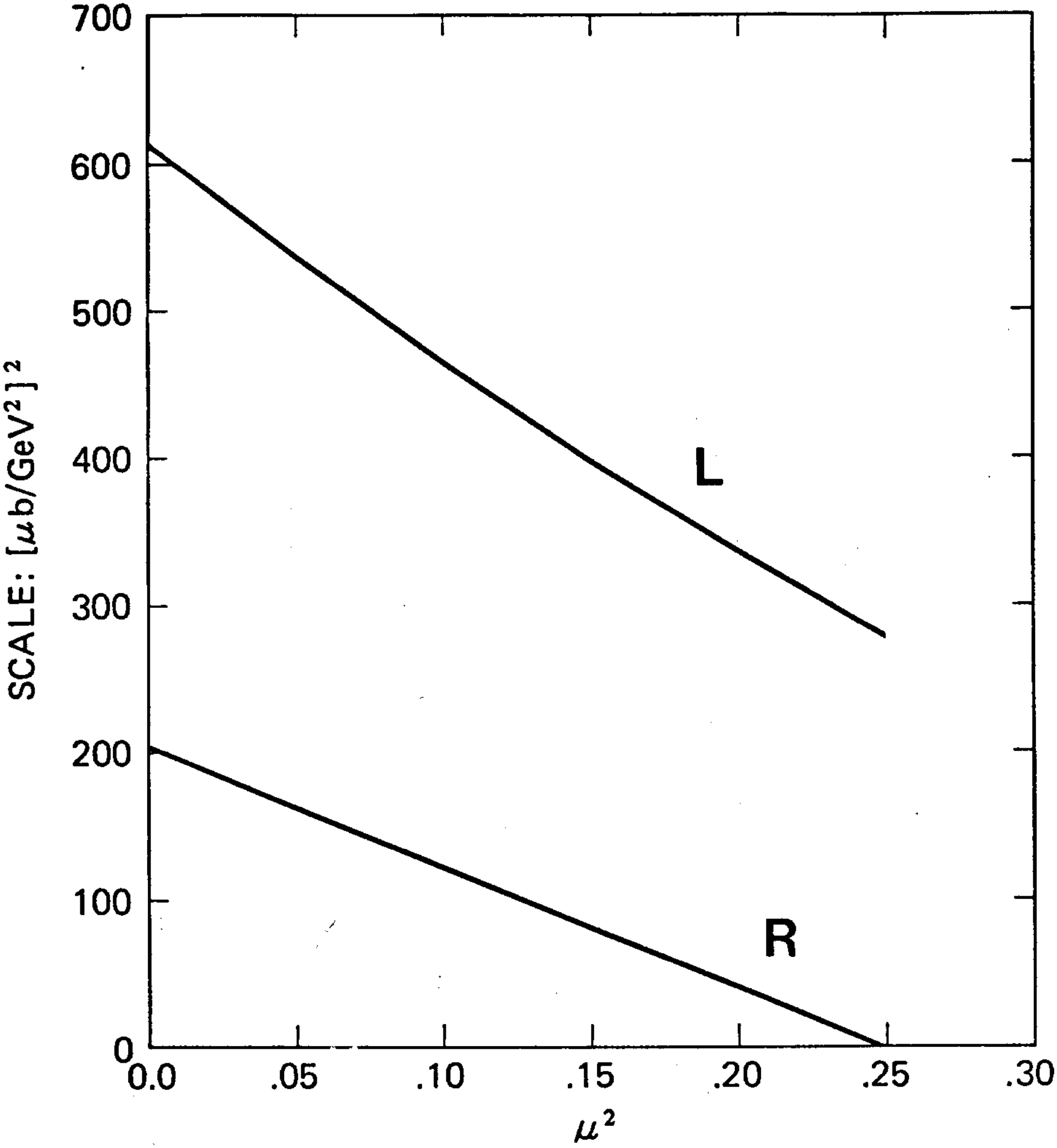
23. B. Kayser, H. Lipkin , and S. Meshkov, to be submitted for publication.

24. We assume here that the baryon trajectories depend on u, not $\sqrt{u}$.

FIGURE CAPTIONS

1. The left-hand side (L) and right-hand side (R) of constraint (3.3) as functions of μ^2. The constraint is always violated.

2. Angular distribution for $\pi^- p \to \Lambda K^0$ at 6.2 GeV/c. The curve assumes that exchange degeneracy between the γ and α contributions is broken by a constant ratio of 5.07. Data from Ref. 3.



700
600
500
400
300
200
100
0
SCALE: [μb/GeV²]²
L
R
0.0
.05
.10
.15
.20
.25
.30
μ²

FIG. 1

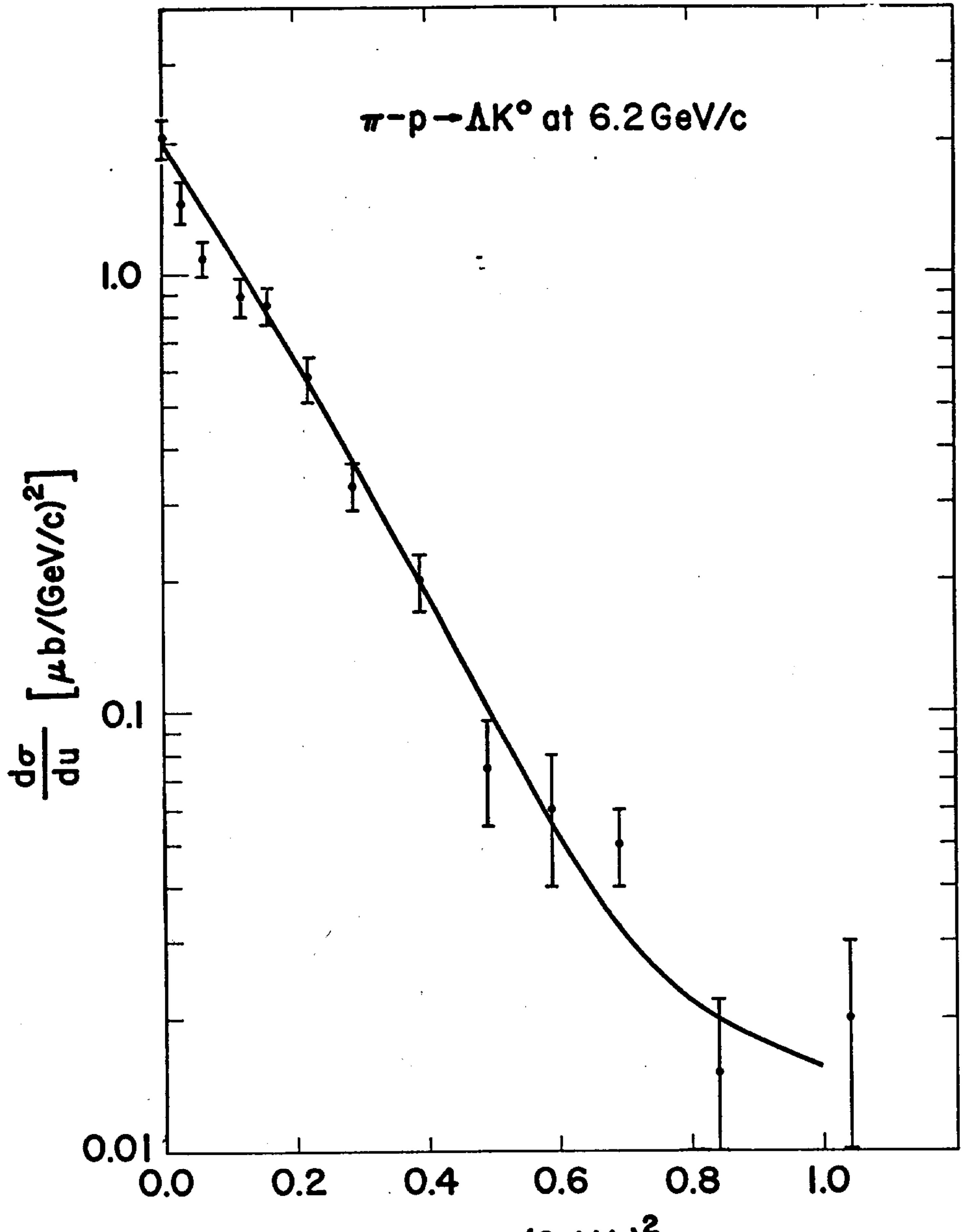


FIG. 2